CURRENT TASKS

White Sands Test Facility

Task

Voluntary Consensus Organization Standards for Nondestructive Evaluation of Thin-Walled Metallic Liners and Composite Overwraps in Composite Overwrapped Pressure Vessels
(FY12 New Start)

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Background

NASA fracture control requirements outlined in NASA-STD-5009 [1] and NASA-STD-5014 [2] are predicated on the availability and use of sensitive nondestructive evaluation (NDE) methods that can detect and monitor defects[1] [3], thereby providing data that can be used to predict failure or reduce the risk of failure in fracture critical components. However, in the case of composite materials and components, including composite overwrapped pressure vessels (COPVs), the effect of defects is poorly understood, the NDE methods used to evaluate locate and size defects are typically at lower technical readiness level than analogous NDE methods used for metals, and demonstration studies to verify the probability of detection (POD) are generally lacking or unavailable. These factors together make failure prediction of fracture critical composite materials and components based on size, quantity, or orientation of defects nearly impossible. Also, when inspecting metal liners in as-manufactured COPVs, sensitivity is lost and only the inner surface of the liner is accessible. Also, NDE of COPVs as applied during

[1] A defect is defined as one or more flaws whose aggregate size, shape, orientation, location, or properties do not meet specified acceptance criteria and are rejectable.

manufacturing varies significantly from manufacturer to manufacturer and has not yet been standardized. Although requirements exist to perform NDE immediately after manufacturing to establish initial integrity of the parts [1, 2, 4], procedural detail for NDE of composites is still nonexistent or under development [5]. For example, in practice, only a visual inspection of COPVs is performed during manufacturing and service, leaving in question whether defects of concern, for example, bridging, overwrap winding anomalies, impact damage below visible threshold, out-of-family strain growth, and liner buckling have been adequately detected and monitored.

To address these shortcomings, in 2005 the NASA Nondestructive Evaluation Working Group (NNWG) began funding work to develop and adopt standards for nondestructive evaluation of aerospace composites in collaboration with the American Society for Testing and Materials (ASTM) Committee E07 on Nondestructive Testing. Similarly, in 2006 the NASA Engineering and Safety Center (NESC) recommended that nondestructive evaluation methods that can predict composite failure in COPVs should be developed and verified, and integrated into the damage control plan for these vessels.

Objectives

The overall objective of this project will be to promulgate NDE procedure detail that has a foundation in experience (i.e., Standard Practices), that upon further elaboration and refinement can evolve into a more quantitative procedures that produce numerical results that are subject to Precision & Bias considerations (repeatability and reproducibility) and that can serve as the basis for Accept/Reject criteria for COPVs (i.e., Standard Test Methods).

Specifically, two ASTM Standard Practices for NDE of COPVs will be developed, one for metal liners and the other for composite overwraps. These two Standard Practices will contain NDE procedural detail describing application of various NDE methods during manufacturing and service, Also, the two Standard Practices will document the inspection considerations that are unique to COPVs. The intent of the two standards will not to be to generate numerical results that can be used as Accept/Reject criteria, but rather, to provide a how-to description of the NDE methods that can be used to generate numerical results that upon further vetting can be used in Accept/Reject criteria.

Approach

The Standard Practices developed will be linked directly to over-arching NASA fracture control requirements documents [1-2, 4-5]. Whenever possible, verification of any numerical results produced by a given NDE method will be based on suitable physical reference standards. NDE tests shall also be designed on the basis of either the Point Estimate Method or Probability of Detection Method [1]. To ensure the broadest possible collaboration, participation has been sought from other NASA organizations, commercial aerospace companies, COPV manufacturers, NDE equipment manufacturers, NDE laboratories, and academia (Figure 1).

The Standard Practices developed will focus on the detection of smaller cracks or crack-like flaws than are specified using Standard NDE methods [1]. The Practices so developed shall be considered Special NDE; and the following requirements shall apply:

1. Other methods aside from ET, PT, RT and UT can be used, for example, AE, shearography and profilometry
2. A 90/95 percent POD capability shall be demonstrated before a Special NDE inspection can be implemented
3. The Special NDE crack size can be any demonstrated size
4. Tests shall be designed on the basis of either the Point Estimate Method or POD Method

Purpose

This project of this project is to develop enabling technologies for NDE of space exploration systems containing composite materials, in particular, COPVs. These technologies will eliminate or mitigate catastrophic burst-before-leak (BBL) and noncatastrophic leak-before-burst (LBB) hazards that pose a risk to existing and future exploration missions, spacecraft and crews. More specifically, this project is the first step in the development of quantitative NDE methods for COPVs such that appropriate engineering controls can be implemented to reduce or avert the risk of LBB and BBL failures. This is especially important for COPVs now used on the International Space Station, some of which have unfavorable long term reliability risk factors. Safety is also improved for COPVs that have been

compromised due to impact, or whose safety margins have been reduced by increased performance or weight saving demands, for example, the push to thin-walled metal liners. The impetus will be the pull of NDE equipment of complex structures, in this case COPVs, to Technical Readiness Level 6, ultimately resulting in development of quantitative Accept/Reject criteria and opening up the possibility of autonomous inspection during service.

Justification

Justification for this project is also found in the Office of Management and Budget (OMB) Circular A–119 [6]. Standards developed by voluntary consensus standards bodies such as ASTM are often appropriate for use in achieving federal policy objectives and in conducting federal activities, including procurement and regulation. The policies of OMB Circular A–119 are intended to:

1. encourage federal agencies to benefit from the expertise of the private sector
2. promote federal agency participation in such bodies to ensure creation of standards that are useable by federal agencies
3. reduce reliance on government-unique standards where an existing voluntary standard would suffice

OMB Circular A–119 was last revised on October 20, 1993. This revision stated that the policy of the federal government, in its procurement and regulatory activities, is to: (1) 'rely on voluntary standards, both domestic and international, whenever feasible and consistent with law and regulation;' (2) 'participate in voluntary standards bodies when such participation is in the public interest and is compatible with agencies' missions, authorities, priorities, and budget resources;' and (3) 'coordinate agency participation in voluntary standards bodies so that the most effective use is made of agency resources and [that] the views expressed by such representatives are in the public interest and do not conflict with the interests and established views of the agencies.'

Customers

This project directly targets the Reliability/Life Assessment/Health Monitoring in the NASA Office of the Chief Technologist Roadmap TA12, Materials, Structures, Mechanical Systems and Manufacturing Materials, Structures, Mechanical Systems and Manufacturing and is crosscutting to other discipline road maps. This project is the first step in promulgating and developing the necessary real time NDE methods that will be used in these integrated health management systems. The International Space Station program, all future manned and unmanned NASA space exploration programs, the Office of the Chief Technologist; plus commercial, Department of Defense, and Department of Transportation concerns utilizing composite overwrapped pressure vessels will benefit from this work. Other NASA partners include the Lightweight Spacecraft Structures & Materials, the NESC, and the Composite Pressure Vessel Working Group.

Metrics

Progress toward adopting the three ASTM Standards and two ASTM Work Items shall be detailed in annual status presentations made to the NNWG and/or OSMA quad charts, with metrics provided for comparison to the original project plan. No final report is anticipated; rather the approved standards shall be the metric of evaluation. Progress presentations and charts shall describe any and all relevant balloting issues and give status for proposals for any ASTM E07 standards development work anticipated beyond FY 2013.

Products

- Annual status reports and presentations
- Formal adoption of two ASTM Standard Practices on NDE of COPVs originating from WK 29034 and WK 29068
- 5-year re-approvals of ASTM E2580-07, E2581-07, E2582-07
- A go/no-go decision on follow-on ASTM-related effort for FY14 and beyond

Major Accomplishments to Date

Six ASTM standards by been adopted for nondestructive flat panel composites and related structures: ASTM E2580-07 [7], E2581-07 [8], E2582-07 [9], E2533-09 [10], and E2662-09 [11], and

E2661-10 [12]. Also, two ASTM work items have been formally registered (WK 29034: *Draft Standard for Nondestructive Evaluation of the Composite Overwrap* [13], WK 29068: *Draft Standard for Nondestructive Evaluation of Thin-Walled Metallic Liners* [14]) (Figure 2). Writing teams have been assembled and draft Standards written for WK 29034 and 29068.

In general, the COPVs covered have metal liner thicknesses less than 2.3 mm (0.090 in.), fiber loadings in the composite overwrap greater than 60 percent by weight. Also, the focus is on high pressure COPVs used for storing compressed gases at MAWPs up to 400 bar (6,000 psia).

WK29034 contains NDE procedural detail for characterization of the composite overwrap in COPVs using the following established methods: acoustic emission (AE), shearography, ultrasonic testing (UT) and visual testing (VT). Also, although WK29034 focuses on COPVs used at ambient temperature, it also has relevance to 1) composite pressure vessels (CPVs) with polymeric liners, and 2) COPVs and CPVs used at cryogenic temperature.

WK29068 contains NDE procedural detail for the characterization of metal liners in COPVs using the following established methods: AE, eddy current testing (ET), leak testing (LT), penetrant testing (PT), radiographic testing (RT), UT, and laser profilometry. Also, WK29068 has relevance to monolithic metallic pressure vessels used in low pressure application for storing liquid propellants at maximum allowable working pressures (MAWPs) up to 35 bar (500 psia).

FY12 and FY13 Plans and Future Work

The 5-year re-approval of ASTM E2580-07, E2581-07, E2582-07 will be accomplished during FY12. The initial balloting of WK 29034 and WK 29068 will also be accomplished during FY12, and the formal adoption of two ASTM Standards originating from WK 29034 and WK 29068 will be accomplished by the end of FY13 (Figure 3, next 6 months highlighted in yellow).

Efforts are currently underway in collaboration with ASTM subcommittee E07.10 Task Group on NDE of Aerospace Composites to define carry-on FY14 effort. Based on results of NESC NDE TDT survey to determine needs for additional ASTM Standards for NDE of composites, the top area of future effort identified was a Standard on NDE of polymer matrix composite degradation and damage from various environmental attacks, impact, and heat. Another area identified for future effort was a Standard on in-situ NDE/Structural Health Monitoring (SHM) of polymer composites and structures, which could have relevance to 1) NASA light weight composite structures, 2) ablative heat shields, and 3) composite repairs/repair patches.

Figure 1. Collaborative NASA-industry approach used in ASTM nondestructive evaluation of composite overwrapped pressure vessel standards development.

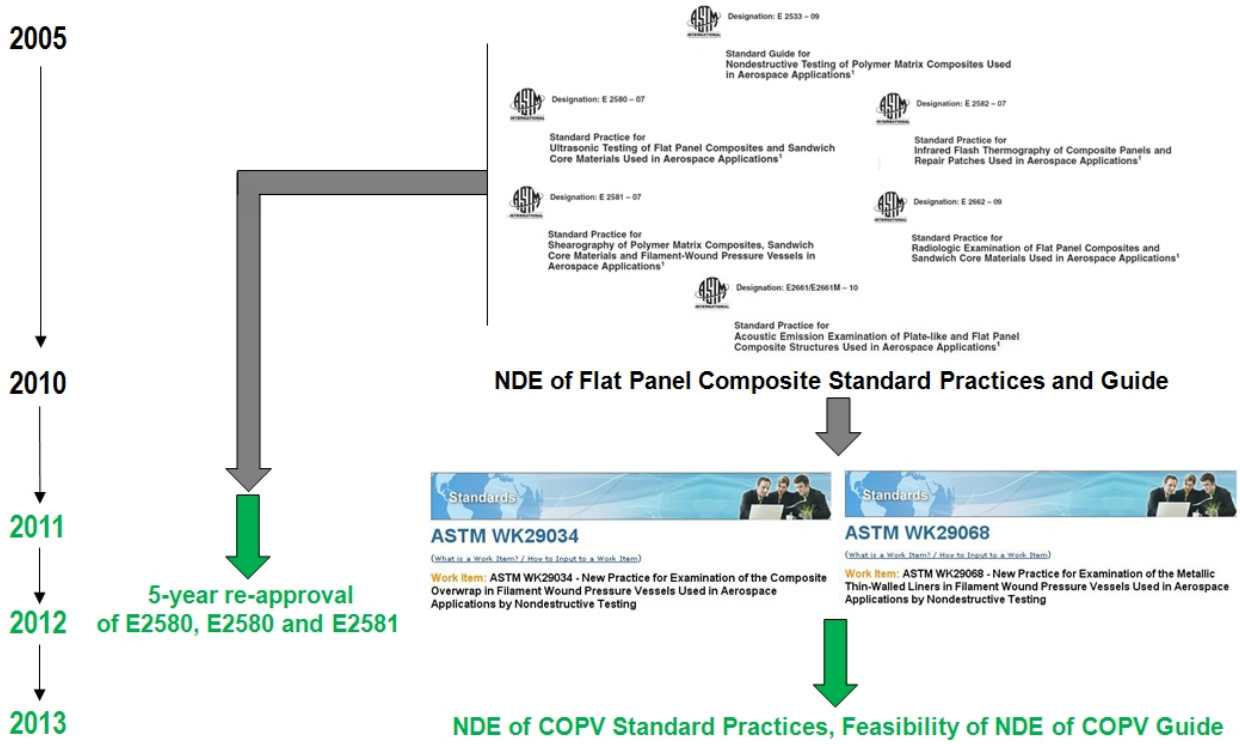

Figure 2. Accomplishments since 2005 and Current Plan.

Milestone	Description	Milestone Date
1	a) Status ASTM E07 and technical writing teams on draft progress b) Initiate 5-year re-approval cycle for E2580-07, E2581-07 and E2582-07 c) Establish feasibility of new Standards for NDE of composites	1/2012
2	Submit WK29034 and 29068 to ASTM for first round of S/C balloting	2-3/2012
3	a) Re-approval *without* change: POCs submit E2580, E2581 and E2582 to ASTM for first round of balloting b) Re-approval *with* change: POCs begin revision of E2580, E2581 and E2582	2/2012
4	Status ASTM E07 and technical writing teams on balloting progress	6/2012
5	Submit revised standards for third round of balloting (S/C or main), including re-balloting of E2580-07, E2581-07 and E2582-07	10/2012
6	a) Status ASTM E07 and technical writing teams on balloting progress b) Status NNWG on FY12/current accomplishments c) Propose NNWG FY14-on effort (if needed)	1/2013
7	Respond to Spring balloting call as needed	3/2013
8	Status ASTM E07 and technical writing teams on balloting progress, resolve any last negatives	6/2013
9	a) Secure formal adoption by ASTM of 2 Standards on NDE of COPVs b) Obtain re-approval of E2580-12, E2581-12 and E2582-12	8/2013
10	Disband E07.10 TG on NDE of Aerospace Composites, or define carry-on effort for FY14 onwards	9/2013

Figure 3. Fiscal Year 2012 and 2012 Milestones and Schedule.

References

1. NASA-STD-5009, Nondestructive Evaluation Requirements for Fracture Critical Metallic Components. Available from the NASA Technical Standards System at the NASA website www.standards.nasa.gov.
2. NASA-STD-5014, Nondestructive Evaluation (NDE) Implementation Handbook for Fracture Control Programs Available from the NASA Technical Standards System at the NASA website www.standards.nasa.gov.
3. ASTM, Standard Terminology for Nondestructive Testing), E1318, American Society for Testing and Materials, West Conshohocken, PA (2005).
4. George C. Marshall Space Flight Center, Fracture Control Requirements for Composite and Bonded Vehicle and Payload Structures, MSFC-RQMT-3479, Baseline revision, Marshall Space Flight Center, Alabama 35812, June 29, 2006.
5. NASA-STD-5013, Nondestructive Evaluation Requirements for Fracture Critical Composite Components, draft standard, 2006.
6. Federal Register, Part IV Executive Office of the President, Office of Management and Budget (OMB) Circular A-119, "Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities," Federal Register, Vol. 63, No. 33, Thursday, February 19, 1998, p. 8546.
7. ASTM, *Standard Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications*, E 2580, American Society for Testing and Materials, West Conshohocken, PA (2007). (5-year revision WK36078 initiated 1/19/12).
8. ASTM, *Standard Practice for Shearography of Polymer Matrix Composites, Sandwich Core Materials and Filament-Wound Pressure Vessels in Aerospace Applications*, E 2581, American Society for Testing and Materials, West Conshohocken, PA (2007).
9. ASTM, *Standard Practice for Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications*, E 2582, American Society for Testing and Materials, West Conshohocken, PA (2007).
10. ASTM, *Standard Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications*, E 2533, American Society for Testing and Materials, West Conshohocken, PA (2009).
11. ASTM. *Standard Practice for Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications*, E 2662 American Society for Testing and Materials, West Conshohocken, PA (2009).
12. ASTM. *Standard Practice for Acoustic Emission Examination of Plate-like and Flat Panel Composite Structures Used in Aerospace Applications*, E 2661/2661M, American Society for Testing and Materials, West Conshohocken, PA (2010).
13. ASTM. *New Standard Practices for Examination of the Composite Overwrap in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing*, WK 29034, American Society for Testing and Materials, West Conshohocken, PA (in draft stage).
14. ASTM. *New Standard Practices for Examination of the Thin-Walled Metallic Liners in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing*, WK 29068, American Society for Testing and Materials, West Conshohocken, PA (in draft stage).